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Evaluating Uncertainty in the Volumes of Fluids in Place in an Offshore Niger Delta Field

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Abstract
The purpose of this work is to evaluate the uncertainty in the volumes of fluids in place in Fault Block A (Segment 3) of the G-1 Sands in the OND field located offshore Niger Delta. This would aid in business decision making and limiting risks which impacts in the development of a successful hydrocarbon exploration and exploitation program. The evaluation was performed in three parts: The first part was executed by building a grid-based model of the reservoir using Eclipse & Petrel. A 100 x 60 x 4 grid was built & faults were created in the model which delineated the reservoir into six segments. The second part of the study involved the calculation of petrophysical properties that affect the volumes of fluids in place & distributing them in the model. This was done by assigning various probability distribution functions to porosity, water saturation and net-to-gross; and calculating STOOIP for the three hydrocarbon zones using Monte Carlo simulation. One hundred realizations of STOOIP were generated for each zone in the reservoir. In the third part of the study, these realizations were plotted as histograms to determine the P10, P50 & P90 values of STOOIP, and these values showed that there was a general decrease in these values for each zone with increase in depth. This methodology can be applied to other reservoirs for proper planning in new and existing field development, as well as the understanding of management risks.

Keywords: model, petrophysical properties, uncertainty, histograms, reservoir, oil-water-contact, hydrocarbon zones

INTRODUCTION

Reservoir Characterization is a process of integrating various qualities and quantities of data in a consistent manner in order to describe reservoir properties of interest in inter well locations (Ezekwe and Filler, 2005). The main purpose of reservoir characterization is to generate a more representative geologic model of the reservoir properties. Thus, in building a Geologic representation of what a reservoir is most likely to be, it is necessary to adequately capture the uncertainty associated with not knowing its exact picture (Odai and Ogbe, 2010).

What do we mean by uncertainty? It means being less than 100% sure about something. In the petroleum industry, people are extremely concerned about quantities such as original hydrocarbon in place, reserves, and the time for the recovery process, which are all critical to the economic returns. Those quantities play a key role in making important decisions for both the oil producers and the investors at different phases of reservoir development. However, being certain of these quantities is usually impossible (Zhang, 2003).However, the main challenge in reservoir development is the availability of limited data and huge uncertainty. Thus, this makes the evaluation of reservoir uncertainty very important in achieving a good understanding of reservoir management risks. Hence, the use of a practical method for estimating uncertainty without compromising accuracy is therefore clearly needed.
Often times, at the discovery of a new field or extension of an existing field, there are uncertainties associated with quantifying the amount of hydrocarbons in place (Akinwunmi*et al*., 2004). These uncertainties may be related to the structure, aerial extent of the accumulation, unseen fluid contacts to delineate the vertical extent, internal architecture of the reservoir and the characteristics of the resident fluids. Consequently, this has made it a routine in field development planning, to identify and quantify the impact of major subsurface uncertainties such as the hydrocarbon in-place volumes and their distribution (Akinwunmi*et al*., 2004).

Other uncertainties encountered in reservoir engineering models as listed by Akaeze*et al*. (2000), includes: drive mechanism, permeability, aquifer support, fluid properties, reservoir extent and connectivity, end point saturations and reservoir structure. Subsequently, evaluating uncertainty using conventional methods, where model parameters are changed individually, makes it impossible to establish an objective business decision without underestimating the effects of uncertainty. Thus, decision making in the face of uncertainty becomes a problem which is usually encountered at every strategic level within the exploration and production value chain. Also, this problem is obvious in new field development projects when there is limited and uncertain geologic and engineering data. As such, it becomes pertinent to develop a systematic methodology for accounting for uncertainty during reservoir characterization and reservoir modeling in an offshore field.Also noted by Zhang (2003), is the fact that uncertainty comes from several sources: measurement error, mathematical model error, and incomplete data sets. All field and laboratory measurements, such as production and PVT data, involve some degree of error or inaccuracy, which may result from poor tool calibration or even human error. This kind of error can be reduced to some extent by using more accurate tools or increased human effort, but can never be eliminated.

STUDY OBJECTIVES

The overall objectives of this study are:

- To develop a methodology for evaluating uncertainty in STOOIP.
- To validate this methodology using a case study from an offshore OND field in the Niger Delta.
- To evaluate the uncertainty in the volumes of fluids in place (STOOIP) in the OND field.

Geology and Reservoir Characteristics

The geologic description of the OND patterned after the Meren field, fits into the general deltaic sequence of the Niger Delta as described by Poston *et al*. (1981). A paleogeographic reconstruction of the depositional history shows that the major field pays were deposited in close proximity to a fluvial channel mouth. These sediments were transported by tidal and along-shore currents and re-deposited in a lower-energy regime of a tidal flat to a lower-barrier-bar environment. The sands are moderately well sorted, fine to very fine grain sub-arkosic sandstones and the shales are soft claystones that grade from medium to hard with increasing depth.While, the northern fault blocks A and B is predominantly oil productive, the southern fault block “F” is mainly gas bearing. Subsidiary oil production also has been found in the smaller C, D and E producing segments (Poston *et al*., 1981).

Overview of Uncertainty Evaluation

In the past 10 to 15 years, probabilistic expressions of reserve estimates have been gradually accepted and adopted in the industry (Zhang, 2003). The traditional method involves specifying a deterministic value for the reserve’s estimate, which usually is calculated with a mathematical model. Unlike the probabilistic method, the traditional method does not consider the uncertainty associated with the reserve estimate; it simply takes for granted that the deterministic reserve value is the most likely value. As a matter of fact, when we talk about reserves prediction, we are never completely sure about its correctness: there is always some degree of uncertainty, big or small, associated with it. Therefore, a statistical approach or probabilistic approach is more appropriate for STOOIP prediction.

In Field Development Planning, it is a routine to identify and quantify the impact of major subsurface uncertainties such as the in-place volumes and their distribution (Akinwumi*et al*., 2004).

Uncertainty analysis methods provide new and comprehensive ways to evaluate and compare the degree of risk and uncertainty associated with each investment choice. The result is that the decision-maker is given a clear and sharp insight into potential profitability and the likelihood of achieving various levels of profitability. In this present study, uncertainty analysis for the reserves prediction, refers only to technological uncertainty. Here, the reserve’s distribution is not converted into monetary value distribution, which is usually done in risk analysis. However, the reserves distribution can be converted into net present value distribution once an oil and gas price prediction is made (Zhang, 2003).Uncertainty evaluation methods attempt to reduce the complexity and difficulty of quantifying uncertainty. As stated by Garb (1986), uncertainty analysis methods have some advantages:

- Uncertainty analysis forces a more explicit look at the possible outcomes that could occur if the decision-maker accepts a given development scheme.
- Uncertainty analysis provides a means to compare the relative desirability of various candidate projects.
- Uncertainty analysis is a convenient and unambiguous way to communicate judgments about risk and uncertainty.

MATERIALS AND METHODS

The OND (offshore Niger Delta) field which was my case study is loosely patterned after the Meren field. This field is located on the Western edge of the Niger River Delta about 110 miles South-East of Lagos. It lies about 8 miles offshore in approximately 40feet of water (Thakur *et al*., 1982) and production has mainly been from sand G. Fault block A of the G-1 actually acts as a single producing unit containing both sands G- 1 and G- 2. The reservoirs are composed of sandstone with minor accumulations of authigenic kaolinite (Poston *et al*., 1981). According to Lumley *et al*. (2000), there are six major fault blocks in the OND field, with each block containing dozen reservoir sands with more than 40 total producing sands. The work described here entails modeling the fault block A of the G-1 sands of the OND field (Figure 1).

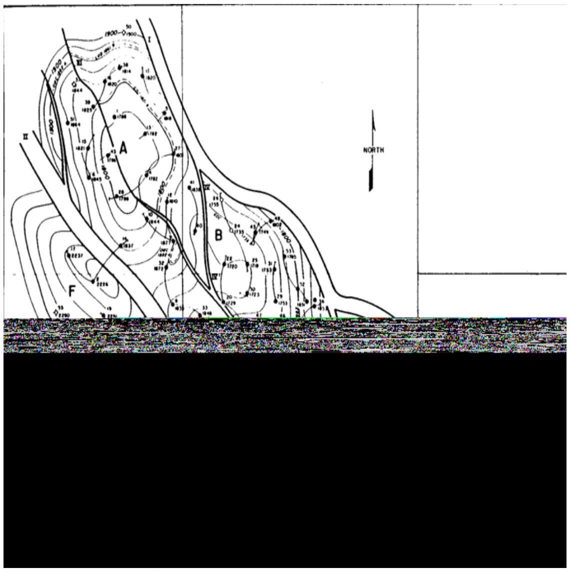

Figure 1: Sand G1 Structure Map (Source: Poston*et al*. 1981)

The methodology used in this study is illustrated in figure 2 and the detailed procedure is described in the following section.

Geological Modeling

The basic inputs in the reservoir characterization process and for the geologic model were the geological skeleton, faults polygons for all major faults, petrophysical properties such as porosity, saturation, net-to-gross, thickness, area and Oil formation volume factor. Permeability was not included here because it actually has no effect on STOOIP. The structural map was digitized and gridded. Codes for each grid, area and zones were written and the grid file was imported into the Petrel platform.

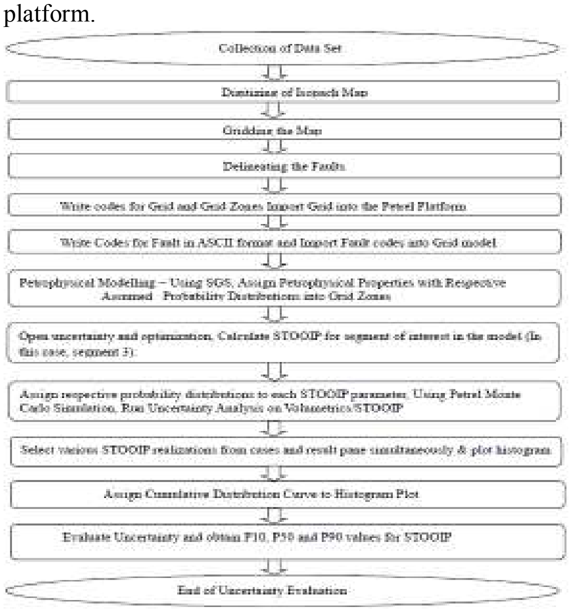

Figure 2: Workflow Used in the Grid-based Geologic Modeling and Uncertainty Evaluation

Horizon and Zone Modeling

Five horizons were modeled for this reservoir to ensure the proper delineation of the oil section of the reservoir into zones. A total of four zones were created in this reservoir. The first three zones, counting from the top represented the hydrocarbon/oil zones. The fourth zone was considered as the water zone. This method of zonation of the reservoir is to account for reservoir heterogeneity in order to quantify the inherent uncertainties in the volumes of fluids in place (STOOIP) in the OND field.

Fault Modeling

The main geological feature in this field is a system of faults that divides the field into eastern and western sections. The fault systems were modeled as vertical fault surfacessuch that the major segment of interest was delineated, thus dividing the model basically into five fault blocks termed segments**.**Uncertainty evaluation focused on the segment for fault block A (see fig.1) because, fault block A is the most prolific segment of the G-1 sands in terms of oil originally in place and oil production.

Petrophysical Modeling

Various petrophysical properties (Porosity, Net-to-Gross, and Water saturation) were assigned and simulated with the model. The stochastic (SGS) method was used for modeling the distribution of continuous properties in the reservoir model. Porosity was modeled in the G-1 Sand assuming a normal distribution. The mean, standard deviation, minimum and maximum values of porosity for the various realizations were created with the Monte-Carlo sampling method using the Petrel software. It is important to note here that zone 4 is actually the water leg and it was not included in the calculation of STOOIP. A uniform distribution ranging from 0.3 to 1.0 was assumed for the net-to-gross thickness ratio. Then 100 realizations of net-to-gross ratios were generated for each zone to calculate STOOIP. Water saturation distribution at initial reservoir conditions was considered in this study. Water saturation (Sw) was assumed to be uniformly distributed with minimum and maximum values of 0.21 and 0.79 in the hydrocarbon zones.

Uncertainty Evaluation of Volumes of Fluids in Place (STOOIP)

The goal of this work is to evaluate uncertainty of the volume of fluids in place (STOOIP) in the G-1 Sands of the OND field. The STOOIP for each zone was determined from equation 3.1.

$$STOOIP = \frac{7758 * Ar * ht * (N/G) * \Phi * (1 - Swi)}{Boi} \quad (1)$$

Where: Boi = Oil Formation Volume Factor

A_r = Area of reservoir.

N = Net formation thickness

G = Gross formation thickness

h_t = Total formation thickness of the oil zone.
Φ = Porosity of the oil zones.
S_{wi} = Initial water saturation.

The area, gross thickness and oil formation volume factor were kept constant in this work. Using Equation 1, one hundred realizations of STOOIP were generated for each zone. The uncertainty in STOOIP was then evaluated using histogram plots to calculate the P10, P50 and P90 values.A method and procedure for modeling the G-1 Sands of fault block A in the OND field has been presented. The method accounts for the uncertainty in the calculation for STOOIP in an oil reservoir.

RESULTS AND DISCUSSIONS

Uncertain parameters which include: porosity, net-to-gross and water saturation were analyzed and STOOIP values for each simulation case were plotted as histograms. Then, P10, P50 and P90 values **(see Table 1)** were analyzed in order to evaluate the uncertainty in STOOIP. The results of the uncertainty analysis of STOOIP in the G-1 Sands are visualized as histograms with cumulative distribution functions **(see figures 3, 4 &5)**. A cumulative distribution function (CDF) which gives a probability (e.g., probability of $S(x) < s$ for all s) was displayed based on the histogram intervals and the curve drawn from the mid-point. The P10, 950 and P90 levels are shown in the histogram plot when the distribution function was displayed.

STOOIP for Zone 1

Recall Zone 1 is the topmost zone in the G-1 Sands model. The results shown in Table 1 indicate that the P10 value for STOOIP is 17.9MMSTB, P50 value is 45 MMSTB and the P90 value for STOOIP is 104.7MMSTB. The P10 shows a 10% probability of getting a volume of fluids in place lesser than 17.9MMSTB.This is equivalent to a 90% probability of getting a STOOIP greater than 17.9MMSTB.

Table 1: STOOIP of Fault Block A of the G-1 Sands in MMSTB

	STOOIP (MMSTB)		
Percentiles	**P10**	**P50**	**P90**
Zone 1	17.9	45.0	104.7
Zone 2	14.9	37.5	87.2
Zone 3	11.9	30.0	69.8

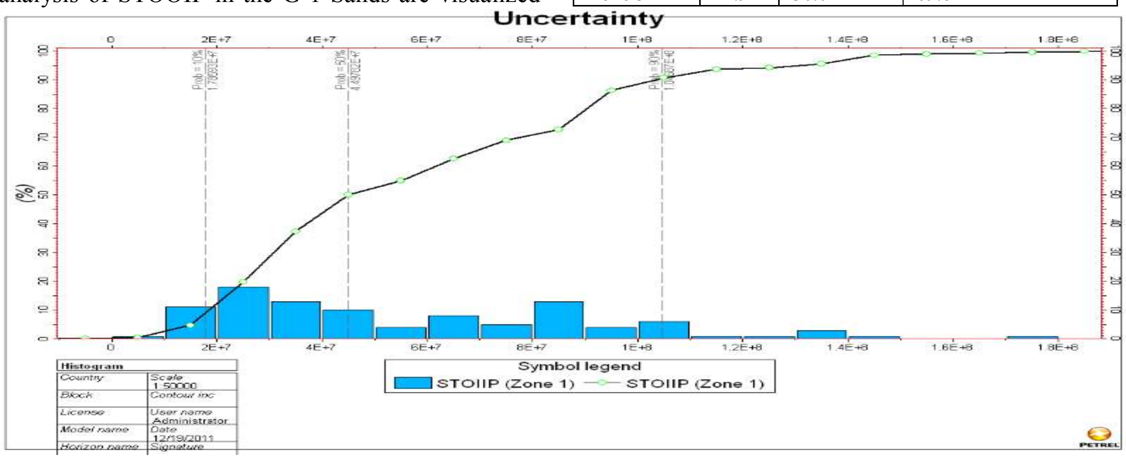

Figure 3: Histogram Plot of STOOIP for Zone 1

STOOIP Results for Zone 2

As shown in figure 4, the STOOIP for Zone 2 ranges from a minimum of 14.99MMSTB for P10 to a maximum of 87.2MMSTB for P90. These results show that Zone 1 of the Fault Block A contains more oil in place than Zone 2 of the G-1 Sands of the OND field.

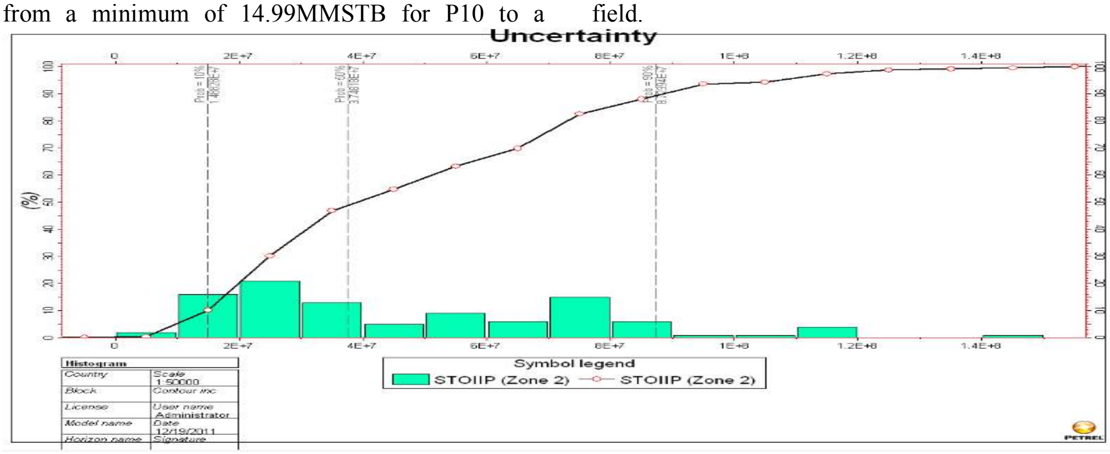

Figure 4: Histogram Plot of STOOIP for Zone 2

STOOIP for Zone 3
Figure 5 shows the results of STOOIP in Zone 3 of the G-1 Sand. The data show that the P10 STOOIP for this zone is 11.9MMSTB; the P50 is 29.8MMSTB, and the P90 is 69.8MMSTB.

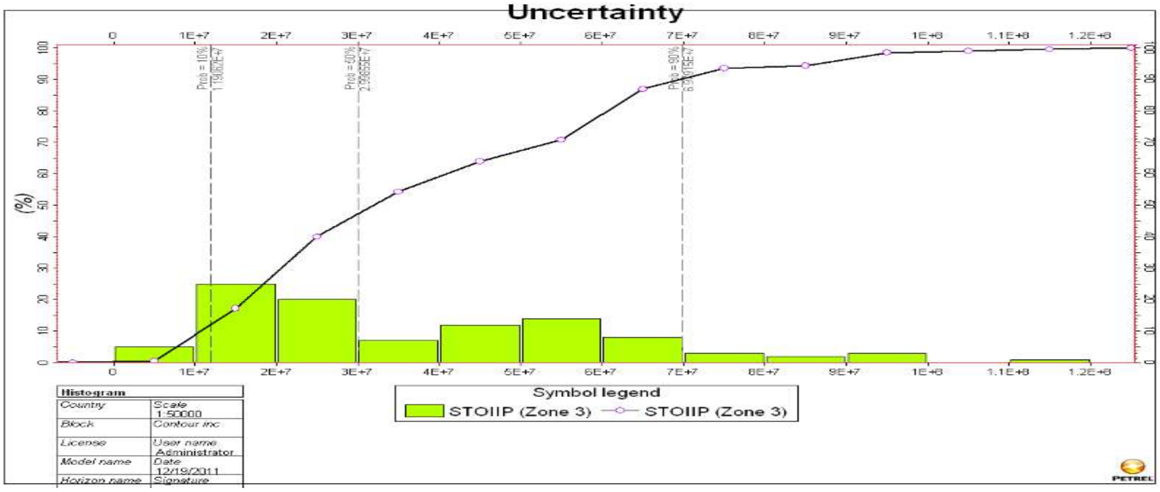

Figure 5: Histogram Plot of STOOIP for Zone 3

A comparison of the STOOIP in Zone2 vs. Zone 3 indicated that Zone 2 of this reservoir contains more oil in place than Zone 3.

Pertinent Remarks
The results of this study show a general gradual decrease in the volume of oil in place (STOOIP with reservoir depth. This is probably because the reservoir properties are degraded with increasing depth. Furthermore, the lower zones which are located close to the water leg (Zone 4) show noticeable decrease in STOOIP.

CONCLUSION
A geologic model has been built for the OND Field. Using a Stochastic method (SGS), petrophysical parameters have been assigned to the grid blocks of the model in Fault block A of the G-1 sands in order to evaluate the uncertainty in STOOIP for the reservoir. Specifically, the following conclusions have been reached.

- The P10 STOOIP in Fault block A of the G-1 sands ranges from 17.9MMSTB in zone 1 to 14.9MMSTB in zone 2 and 11.9MMSTB in zone 3.
- The P50 STOOIP ranges from 45MMSTB in zone 1 to 37.5MMSTB in zone 2 and 30MMSTB in zone 3.
- The P90 STOOIP ranges from 104.7MMSTB in zone 1 to 87.2MMSTB in zone 2 and 69.8MMSTB in zone 3.

These results show a general decline in STOOIP as the depth increases from Zone 1 to Zone 3 in Fault block A of the G-1 sands.This methodology has been validated using a case study with data from an offshore field (OND) in the Niger Delta.

In this work, a grid cell-based methodology was used to evaluate the uncertainty in the volume of oil in place in Fault Bock A of the G-1 Sands. This is limited due to the fact that it does not define the reservoir attributes on a grid block scale and various objects with different shapes and sizes could therefore not be modeled and simulated. However, for extensive reservoir modelingwhere these attributes will be simulated, an object-based conditional simulation modeling method is recommended.

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